Journal of Forestry Research (2012) 23(4): 569−574
DOI 10.1007/s11676-012-0296-7

ORIGINAL PAPER

Seedling survival and growth of *Aquilaria malaccensis* in different microclimatic conditions of northeast India

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Received: 2011-08-15; Accepted: 2011-10-08

Abstract: We studied seedling survival and growth of *Aquilaria malaccensis* in three different environmental conditions (homegardens, green house and in different canopy conditions) of northeast India. Results show that mean seasonal survival was highest in green house (95.53%±2.33), followed by homegardens (89.3%±1.89) and different canopy conditions (77.62%±6.73); the highest values were found during February to April for both the homegardens (96%±1.68) and green house (98% ± 0.88) and lowest during November to January (78%±2.99) in homegardens and May to July (90%±4.53) in green house. In case of transplanted seedlings in different canopy conditions, mean seasonal survival was highest during May to July (98%±1.92) and lowest during August to October (66%±12.81). However, mean seasonal growth of collar diameter was highest in different canopy conditions (23.99%±1.76) compared to green house (21.52%±2.70) and homegardens (12.44%±1.33) and it was highest during rainy season (May to July) and lowest during dry winter (November to January) in all the three experimental sites. These variations may be due to the different microclimatic conditions as well as nutrient status of the soil in all the three experimental sites. Although, seedling quality plays a great role in their survival and growth, based on the result of green house experiment, it can be concluded that maintenance of seedlings in green house conditions during their early growth period may improve both the survival and growth for large scale plantation of the species. Thus, the species can be reintroduced in its natural forest range to compensate the loss of natural population of this precious species in northeast India.

Keywords: *Aquilaria malaccensis*; seedling survival; seedling growth; homegardens; canopy conditions; green house

Foundation project: The project was financially supported by DBT, Govt. of India through the project "Mapping and quantitative assessment of geographic distribution and population status of plant resources of Eastern Himalayan Region".

The online version is available at http://www.springerlink.com

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Responsible editor: Hu Yanbo

Introduction

Aquilaria malaccensis, a red listed tree species of northeast India, is extensively cultivated in the homegardens of upper Assam in association with other plant species for its high price and market demand. This species is known mainly for its resin or agarwood which is used extensively in incense, perfume and traditional medicine. Natural populations of *A. malaccensis* are widely distributed in south and southeast Asia. In India, it occurs mostly in the foothills of northeastern region (Assam, Meghalaya, Nagaland, Mizoram, Manipur, Arunachal Pradesh, Tripura) and West Bengal. Population of the species is decreased in natural forests of northeast India mainly due to unsustainable harvesting of mature trees for the trade of agarwood. Therefore, inter-governmental action has been taken to bring the international trade within sustainable levels and the species is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1994 (CITES, 1994). The species is 'Vulnerable' globally, 'Critically Endangered' in India (IUCN 2010) and almost 'Extinct in wild' in Assam (Anonymous 2003). Therefore, conservation and proper management of the species is of urgent need in the current situation.

Harvesting of mature trees resulted in lack of sufficient seed supply, thereby causing great impact on natural regeneration. Successful regeneration of any plant species depends on right amount of growing space available for seedling establishment and growth (Philips & Gentry 1994). In order to achieve regeneration, the most important factors that play vital role are high rate of seed germination and good survival of seedlings. Performance of seedlings also depends on resource availability and their physiological ability to efficiently use the higher level

of resources (Brokaw 1985). Survival and growth of tree seedlings are determined by the interactive influence of biotic and abiotic factors of the environment (Augspurger 1984). Extreme weather changes and both seasonal and inter annual variability in rainfall affect seedling emergence, establishment and survival (Ray & Brown 1995). The recruitment, survival and growth pattern of tree seedlings in different forest ecosystems have been studied in different parts of the world including India (Denslow 1980; Khan et al. 1986; Rao et al. 1997; Khan & Uma Shankar 2001; Nagamastu et al. 2002). However, no such study is available so far in homegarden species, especially in northeast India. Therefore, a study on the survival and growth of seedlings of *A. malaccensis* in different microclimatic conditions was attempted.

Materials and methods

Survival and growth of seedlings in homegardens

Eight representative homegardens of similar size (four from each district) were selected from Jorhat and Golaghat districts of upper Assam as natural habitat to study the seedling growth and survival of *A. malaccensis*. Homegardens were selected from the pool of agarwood growing areas based on its size, location, vegetation and seedling population. Seedlings were distributed here and there throughout the homegardens. Therefore, seedling survival and growth were studied in eight randomly laid permanent quadrats of 1 m × 1 m size in each homegarden. Sufficient number of seedlings (n = 20–95) were tagged with an individually numbered aluminum tag based on the availability of the seedlings and their growth and survival were recorded at three months interval over a period of two years from February 2008 to February 2010. Seedling growth was studied through non destructive methods in terms of height, collar diameter and number of leaves.

Different environmental parameters (average monthly rainfall, maximum-minimum temperature and relative humidity) of both the Golaghat and Jorhat Districts during different months, from January 2008 to February 2010, were collected from the Sugarcane Research Institute and Agrometeorological Department of Assam Agricultural University of Golaghat and Jorhat District, respectively and shown in Fig. 1.

Survival and growth of seedlings in greenhouse conditions

Seedling growth and survival in green house condition were studied by growing 90 seedlings (30 in each chamber) at three irradiance levels (75%, 50% and 25%) created with shade cloths of different thickness in the green house of Department of Forestry, NERIST (27°07' N and 93°22' E; altitude 128 m). All the seedlings were one-year old nursery raised seedlings of uniform growth and healthy appearance grown in polythene bags filled with farmyard soil and was watered regularly. Each seedling was labeled with an individually numbered aluminum tag and growth was recorded as mentioned before. Additional growth parameters (collar diameter, number of leaves, shoot length, root length and biomass) were estimated by harvesting ten seedlings from each of the three irradiance levels after every three months for one year from August 2009 to August 2010. Each seedling was washed after harvesting and collar diameter, number of leaves, shoot length, root length and fresh weight were measured. Dry weight of the seedlings was then measured after oven-dry at 80°C for 48 hours using electronic balance.

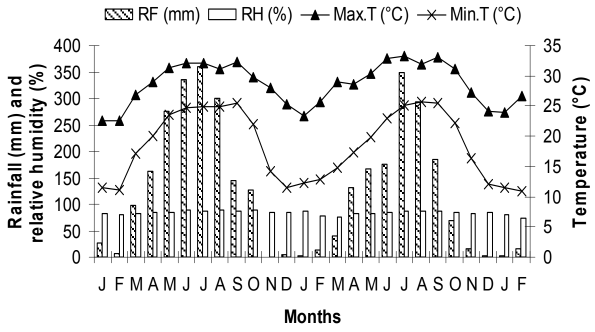

Fig. 1 Total monthly rainfall, average relative humidity and average maximum and minimum temperature of the study sites (Jorhat and Golaghat Districts of Upper Assam) during January 2008 to February 2010.

Survival and growth of transplanted seedlings under different canopy conditions

Growth and survival of transplanted seedlings were studied in four different canopy conditions viz. dense (canopy cover 84%), sparse (canopy cover 60%), open (canopy cover 30%) and without canopy with full sunlight (canopy cover 0%) prevailing in NERIST campus, Nirjuli, Arunachal Pradesh. A total of 120 randomly selected one-year old nursery raised seedlings (30 in each site) of uniform growth and healthy appearance were transplanted one meter apart during peak rainy season (August 2009). Seedlings were similarly labeled with aluminum tag and their growth was evaluated in terms of height, collar diameter and number of leaves at three months interval over a period of one year (August 2009 to August 2010).

Soil of the different transplantation sites of NERIST campus is blackish in colour and acidic in nature. It is rich in organic matter. The texture of the soil is loamy sand and all other environmental parameters of the site are presented in Table 1. Soil temperature was measured by inserting soil thermometer down to 10 cm depth. Besides, water holding capacity of the soil was also recorded following Keens up method. Soil texture was measured by hydrometer method. Soil moisture content was determined by oven drying three samples collected from each site. Canopy coverage was measured by plant canopy analyzer (LI-COR 2000). Photosynthetic active radiation (PAR) was measured by digital light meter (LI-COR 250) at 9 a.m., 12 p.m. and 3 p.m. thrice in a month and mean was calculated. Humidity of air and air temperature were measured using digital thermohygrometer.

Table 1. Environmental parameters of the four different transplantation sites of NERIST campus

Canopy conditions	Photosynthetic active radiation (μmol sec^{-1})	Canopy cover (%)	Mean annual humidity (%)	Mean annual air temperature (°C)	Mean annual soil temperature (°C)	Average soil moisture (%)	Water holding capacity (%)	Soil texture			
Dense canopy	78-644	84	80±1.69	24.5±2.81	21.2±3.26	20.5±2.13	70±8.45	Loamy sand	Sand-79%	Silt-6.5%	Clay-14.4%
Sparse canopy	122-886	60	72±2.47	28.16±4.81	26±3.23	16.41±1.49	67±8.85	Loamy sand	Sand-78.6%	Silt-9.6%	Clay-11.8%
Open canopy	148-970	40	65±3.68	30.33±4.57	27.5±3.73	12.2±0.65	63±10.27	Loamy sand	Sand-82.6%	Silt-7.4%	Clay-10%
No canopy	169-1522	0	58±3.76	32.56±3.68	29.8±3.17	9.23±1.12	56±8.79	Loamy sand	Sand-85.2%	Silt-5.8%	Clay-9%

Results

Survival and growth of seedlings in homegardens

Seasonal seedling survival rate of *A. malaccensis* was not significantly different among the eight selected homegardens during four different seasons of the year. Mean seasonal survival rate of seedling was highest in homegarden 7 (98%±2.50) and lowest in homegarden 6 (81%±6.35) of Golaghat district and it was highest during February to April (96%±1.68) followed by May to July (92%±3.82) and lowest during November to January (78%±2.99) (Fig. 2).

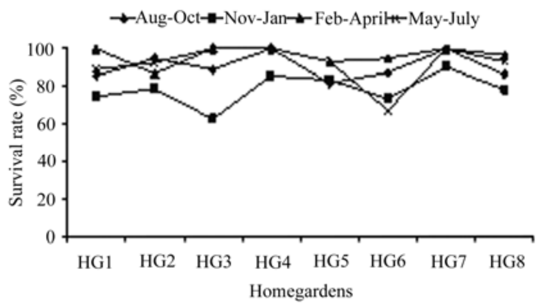

Fig. 2 Survival rate of *A. malaccensis* seedlings in eight selected homegardens of upper Assam during different seasons of the year.

On the other hand, mean seasonal (per three months) growth rate of *A. malaccensis* seedlings in terms of collar diameter varied significantly among the eight selected homegardens ($F_{7,532}$ = 15.35, $p < 0.001$) as well as during four different seasons ($F_{3,532}$ = 19.51, $p < 0.001$) of the year. It was also differed significantly among the individuals growing in homegardens 1, 5, 6 and 8 (HG1: $F_{3,60}$ = 6.48, $p < 0.01$; HG5: $F_{3,52}$ = 3.59, $p < 0.05$; HG6: $F_{3,156}$ = 9.08, $p < 0.001$; HG8: $F_{3,100}$ = 8.09, $p < 0.001$) during four different seasons of the year but not in the remaining four homegardens (homegarden 2, 3, 4 and 7). However, mean seasonal growth rate was highest in homegarden 7 (19.86%±1.42) of Golaghat district and lowest in homegarden 2 (4.73%±0.44) of Jorhat district and it was highest during rainy season (May to July) (18.15%±2.23) and lowest during dry winter (November to January) (7.64%±1.49) (Fig. 3). Growth rate in terms of height and number of leaves was also higher during rainy seasons and decreased substantially during the beginning of dry season and was lowest during entire winter (November to January). District wise study showed significant differences in growth rate ($p < 0.01$) but, seedlings survival rate of *A. malaccensis* showed insignificant differences. Although, the mean seasonal survival was higher in Jorhat district (89.98%±2.16) compared to Golaghat district (88.65%±3.42), mean seasonal growth rate in terms of collar diameter was higher in Golaghat district (12.89%±2.49) compared to Jorhat district (11.48%±2.37).

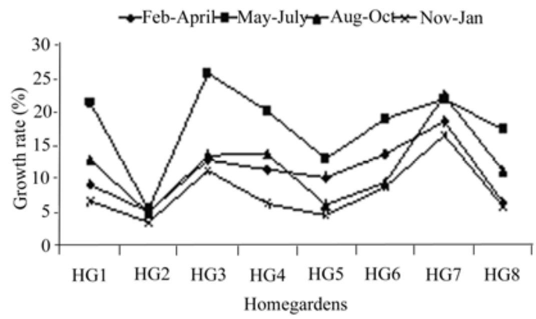

Fig. 3 Mean seasonal growth rate of *A. malaccensis* seedling in terms of collar diameter in eight selected homegardens of upper Assam during different seasons of the year.

Survival and growth of seedlings in greenhouse conditions

Seasonal seedlings survival rate of *A. malaccensis* was not differed significantly among the three irradiance levels of the green house during four different seasons of the year. But, mean seasonal growth rate in terms of collar diameter varied significantly among the three different light irradiance levels of the green house ($F_{2,280}$ = 18.68, $p < 0.001$) as well as during four different seasons ($F_{3,280}$ = 7.34, $p < 0.001$) of the year. It was also differed significantly between the seedlings growing in 25% ($F_{3,100}$ = 8.08, $p < 0.001$) and 50% irradiance levels ($F_{3,124}$ = 3.20, $p < 0.05$) but, the seedlings growing in 75% irradiance level did not show significant differences in growth rate during four different seasons of the year. Both the mean seasonal survival rate and growth rate in terms of collar diameter was highest in 50% irradiance level (survival rate: 99%±1.13 and growth rate: 34.41%±3.04) followed by 25% (survival rate: 97%±1.08 and growth rate: 28.71%±3.31) and 75% irradiance level (survival rate: 91%±3.68 and growth rate: 17.99%±2.95) and survival rate was maximum

during February to April (98%±0.88) and lowest during May to July (90% ± 4.53) (Fig. 4) but, growth rate was highest during May to July (34.47%±5.02) and lowest during November to January (20.56%±4.38) in all the three different irradiance levels of the green house (Fig. 5). On the other hand, growth rate in terms of height and leaf number was also highest in 50% irradiance level and lowest in 75% irradiance level and it was highest during February to April and decreased substantially after the rainy season and lowest during dry winter (November to January).

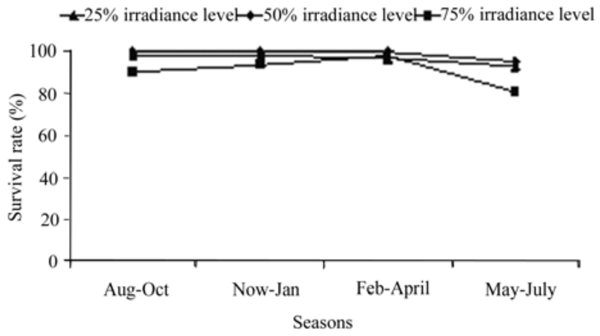

Fig. 4 Seedling survival rate of *A. malaccensis* in three irradiance levels of the green house during different seasons.

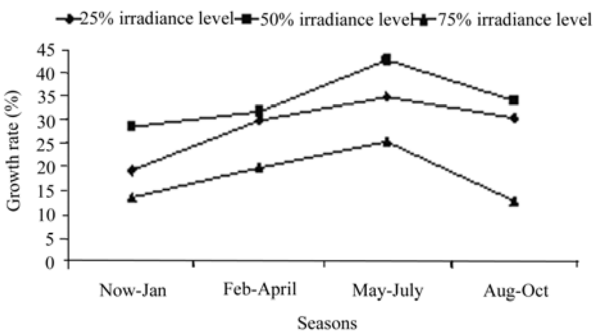

Fig. 5 Mean seasonal growth rate of *A. malaccensis* seedlings in terms of collar diameter in three different light irradiance levels of the green house during different seasons.

Growth of harvested seedlings in terms of collar diameter, leaf number, shoot length, root length and biomass also increased with the increase of the age of the seedlings. Average seasonal growth rate in terms of both root length and biomass accumulation pattern also showed similar results in three irradiance levels of the green house during four different seasons of the year. It was highest in 50% irradiance level (38.53%±10.98; 53.28%±8.02) and lowest in 75% irradiance level (26.93%±8.64; 44.51%±5.84) and it was highest during May to July (57.18%±4.73; 64.66%±4.11) and lowest during November to January (13.26%±1.98; 33.59%±1.54) (Fig. 6 A & B).

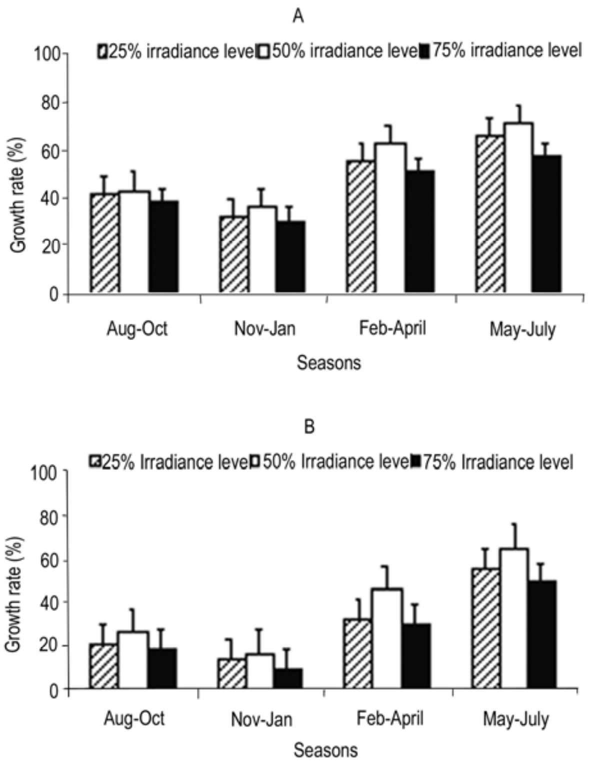

Fig. 6 Mean seasonal growth rate of harvested seedlings of *A. malaccensis* in three different light irradiance levels of the green house during different seasons in terms of A. root length B. biomass.

Survival and growth of transplanted seedlings under different canopy conditions

Transplanted seedlings also showed insignificant differences in seasonal survival rate among four different canopy conditions of NERIST campus as well as during four different seasons of the year. Mean seasonal survival rate was highest in sparse canopy (90%±4.43) and lowest in no canopy (66%±12.79) and it was highest during May to July (98%±1.92) and lowest during August to October (66%±12.81) (Fig. 7). On the other hand, mean seasonal growth rate in terms of collar diameter varied significantly during four different seasons of the year ($F_{3,107}$ = 9.43, $p <$ 0.001) but, it showed insignificant differences among four different canopy conditions of the transplantation sites. It also differed significantly between the seedlings growing in dense ($F_{3,44}$ = 5.58, $p < 0.01$) and sparse canopy ($F_{3,48}$ = 5.41, $p < 0.01$) but, seedlings growing in open and no canopy showed insignificant differences in growth rate during four different seasons of the year. Mean seasonal growth rate in terms of collar diameter was highest in dense canopy (27.95%±4.20) followed by sparse canopy (25.73%±4.04) and lowest in no canopy (20.12%±3.32) (Fig. 8) and it was highest during May to July (33.29%±2.31) and lowest during November to January (16.38%±1.59). This may be attributed to higher rainfall, humid weather and other favorable microclimatic conditions during May to July.

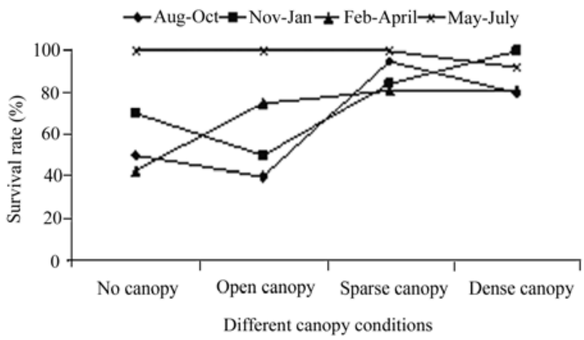

Fig. 7 Survival rate of transplanted seedlings of *A. malaccensis* in different canopy conditions of NERIST campus during different seasons.

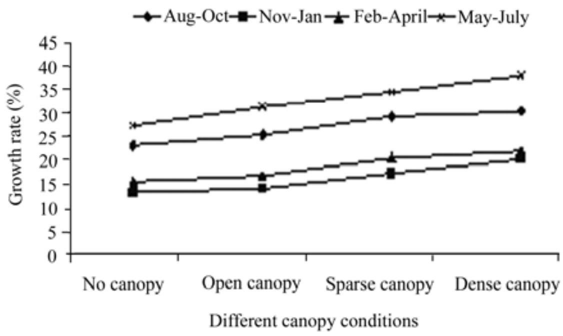

Fig. 8 Mean seasonal growth rate of transplanted seedlings of *A. malaccensis* in terms of collar diameter in different canopy conditions of NERIST campus during different seasons.

Discussion

Seasonal changes in the prevailing environmental conditions affect the growth and survival of the seedlings. The present study showed that seedling survival and growth varied greatly in different microhabitats during different seasons of the year. Lowest seedling growth and survival during winter season (November to January) in all the microhabitats may be primarily due to limited rainfall during this season (Schulte & Marshall 1983; Khan et al. 1986; Kumar et al. 1994; Khumbongmayum et al. 2005). On the other hand, better growth performances during rainy seasons may be because of favorable growing conditions and increased availability of soil moisture and nutrient due to rapid decomposition of leaf litter (Khumbongmayum 2004). Similar findings were also reported from sacred groves of Manipur, NE India (Khumbongmayum et al. 2005) and tropical dry forest in Ghana (Lieberman & Li 1992). Out of the all three different microhabitats, highest seedling growth was observed in transplantation sites, this may be because of favorable microclimatic conditions prevailing in the site. On the other hand, poor seedlings survival of *A. malaccensis* was observed in homegardens and in different transplantation sites compared to green house conditions; this was probably due to competition with associated species. Upadhaya et al. (2009) also reported poor growth and low survival rate of *Ilex khasiana* seedlings in natural forests of Meghalaya, northeastern India due to competition with associated species. The present investigation revealed that *A. malaccensis* seedlings survive and grow better in low and intermediate light conditions of both the transplantation site and the green house and both the growth and survival was poor in high light conditions. Therefore, the species may be categorized as shade tolerant species (Baker 1949). Variation in seedling growth in different microclimatic conditions may be due to the differences in growth behavior under given set of environmental conditions. This may be due to specific attributes of the species to influence the physiological ability and utilize the available resources efficiently. It may also directly relate to the way in which species can adjust to their morphological and physiological characteristics of the environment.

Among all the eight selected homegardens, highest seedling survival and growth was recorded in homegarden 7 of Golaghat district; this may be because of the less abundance of both *A. malaccensis* and other associated vegetations and hence, low competition for available resources. Again, in green house experiment, better growth and survival of the seedling was observed in intermediate (50% irradiance level) and low (25% irradiance level) light conditions compared to high irradiance level (75% irradiance level) as *A. malaccensis* is an understory tree species (Saikia et al. 2012). In the present experiment, relatively vigorous growth and development was observed in dense canopy conditions which may be attributed to the microclimatic condition (e.g. low light intensity, moderate temperature, high humidity, better water holding capacity and soil moisture etc. compared to the other transplantation sites) favourable for the growth of *A. malaccensis* seedlings. Plants grown in full sunlight suffer from limitation of low soil moisture, minimum water holding capacity and high temperature, high light intensity which affects the growth and survival of the seedlings. Bhuyan (2002) also reported lowest relative growth of *Elaeocarpus ganitrus* seedlings in full sunlight conditions compared to the intermediate light. Seedlings needs lots of shade during their early growth period for better survival and growth which can be understand from both the green house and transplantation experiments.

Seedling mortality was recorded by different causes at different stage of growth in all the microhabitats. In early stages of growth, seedling mortality was mainly due to damping off diseases. However, mortality at later stages of growth was primarily due to insect damage and drought stress during dry winter season. Grasshopper (*Bacillus rossii* Fabr.) and caterpillar larva (*Heortia vitessoides* Moore) were identified as two major insect pests which may retard the survival and growth of seedlings during different seasons of the year. Caterpillar larvae were found to consume almost all the leaves of the seedlings during specific season (mid April to August) but, grasshopper used to present throughout the year. Trampling on the seedlings by cattle and human being, uprooting of seedlings by human and cutting of seedlings during maintenance were other common causes of seedling mortality in homegardens. Khan and Tripathi (1991) also reported damping off diseases of seedlings as an important

cause of seedling mortality during early stages of growth in sub-tropical humid forest stands of northeast India due to higher relative humidity in the region. Soehartono et al. (2002) reported trampling and cutting being one of the main causes of seedling mortality in *A. malaccensis* in natural forest in West Kalimantan, Indonesia. On the other hand, Beniwal (1989) observed severe insect attack on seeds and seedlings of the same species in natural forests of northeast India. Insect herbivory as a common cause influencing the establishment and survival of tree seedlings were also reported from northeast India (Khan & Tripathi 1991) and elsewhere (Clark & Clark 1985; Sork 1987).

Conclusions

A. malaccensis showed considerable variation in survival and growth in green house condition, transplantation sites and homegardens. Highest seedling survival in green house compared to its natural habitat and transplantation sites was observed in this study. Although, seedling quality plays a great role in their survival and growth, based on the result of green house experiment, it could be suggested that seedlings maintained in controlled environments during early growth period may improve survival and growth for large scale plantation of the species. Similarly, from transplantation experiment in different canopy conditions, it can be concluded that plantation of *A. malaccensis* should be raised as understory under the established forests/plantations with small canopy gaps or in slightly shaded localities for better success. Based on the findings of the present research, the species can also be reintroduced in its natural forest range to compensate the loss of natural population of this precious species in northeast India.

Acknowledgements
We are thankful to Bironjoy, Bijit and Samar for their assistance during the experiment periods.

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